

# AIRS L1b Radiometric Calibration and Accuracy Update

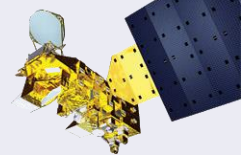
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# AIRS Designed for High Spectroradiometric Resolution, Accuracy and Stability

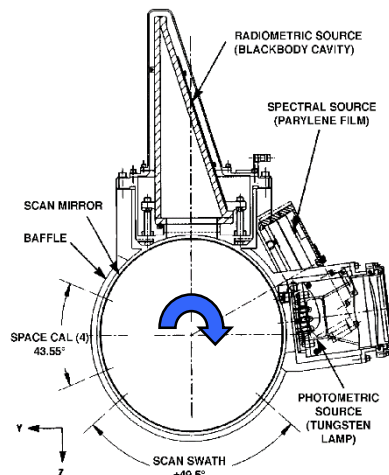


## AIRS Features

- Orbit: 705 km, 1:30pm, Sun Synch
- Pupil Imaging IFOV :  $1.1^\circ \times 0.6^\circ$   
(13.5 km x 7.4 km)
- Scanner Rotates about Optical Axis  
(Constant AOI on Mirror)
- Full Aperture OBC Blackbody,  $\epsilon > 0.998$
- Full Aperture Space View
- Solid State Grating Spectrometer
- Temperature Controlled Spectrometer: 158K
- Actively Cooled FPAs: 60K
- No. Channels: 2378 IR, 4 Vis/NIR
- Mass: 177Kg,  
Power: 256 Watts,  
Life: 5 years (7 years goal)



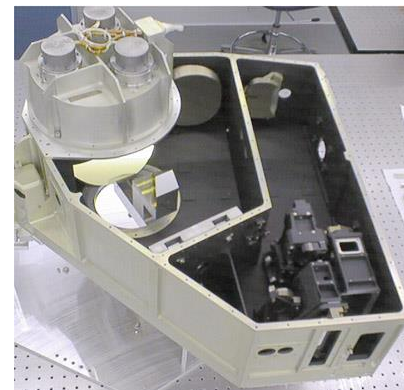
**Active Detector Cooling**



**Isolated Scan Cavity**



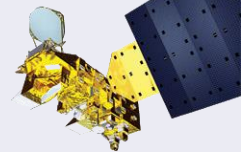
**Temperature Controlled Instrument**



**Grating Spectrometer**

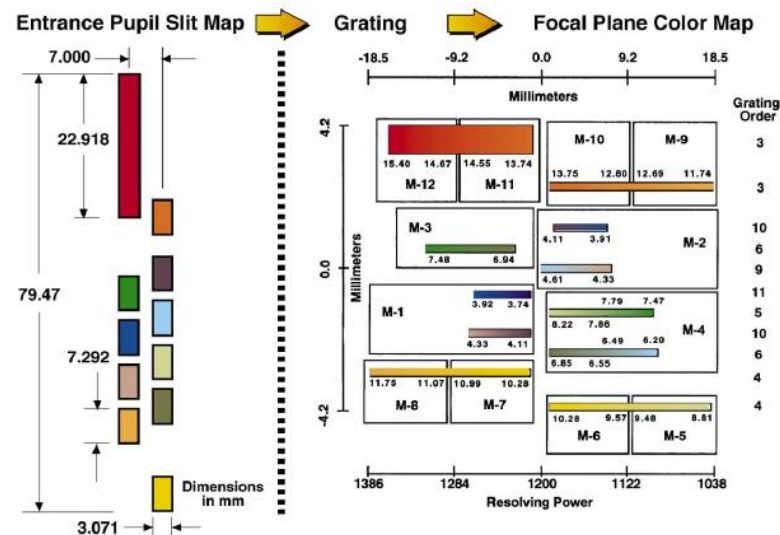
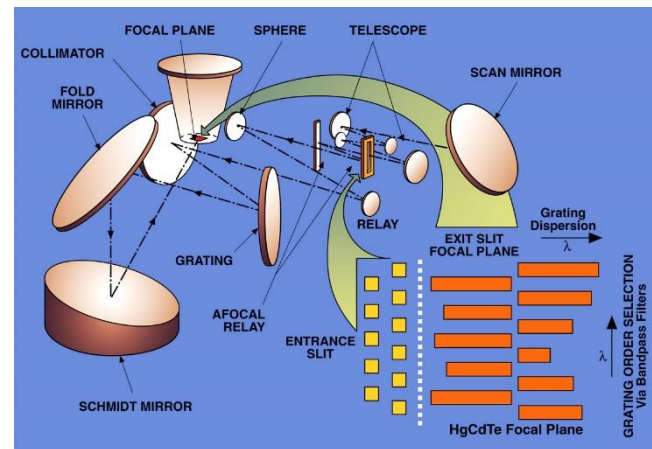
IR Spectral Range:  
3.74-4.61  $\mu\text{m}$ , 6.2-8.22  $\mu\text{m}$ ,  
8.8-15.4  $\mu\text{m}$   
IR Spectral Resolution:  
 $\approx 1200 (\lambda/\Delta\lambda)$   
No. IR Channels: 2378 IR

# AIRS Spectral Bands Defined by 11 Entrance Apertures and 17 Detector/Filter Modules

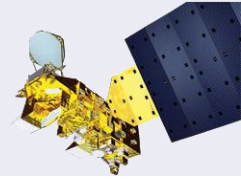


AIRS Module Spectral Band Limits

		$\lambda_1$	$\lambda_2$	$\nu_1$	$\nu_2$
		( $\mu\text{m}$ )	( $\mu\text{m}$ )	( $\text{cm}^{-1}$ )	( $\text{cm}^{-1}$ )
1	M1a	3.752	3.934	2541.9	2665.2
2	M1b	4.127	4.348	2299.8	2422.8
3	M2a	3.891	4.088	2446.2	2569.8
4	M2b	4.301	4.584	2181.5	2325.0
5	M3	6.930	7.473	1338.2	1443.1
6	M4a	6.196	6.489	1541.1	1613.9
7	M4b	6.549	6.848	1460.3	1527.0
8	M4c	7.469	7.786	1284.3	1338.9
9	M4d	7.858	8.217	1217.0	1272.6
10	M5	8.798	9.469	1056.1	1136.6
11	M6	9.558	10.269	973.8	1046.2
12	M7	10.264	10.974	911.2	974.3
13	M8	11.065	11.744	851.5	903.8
14	M9	11.731	12.670	789.3	852.4
15	M10	12.790	13.735	728.1	781.9
16	M11	13.728	14.543	687.6	728.4
17	M12	14.663	15.394	649.6	682.0



# AIRS Radiometric Transfer Equations Used to Identify Error Terms



## Radiometric Transfer Equations

$$N_{sc,i,j} = \frac{a_o(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_2(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos 2(\theta_j - \delta)}$$

$$a_o(\theta_j) = P_{sm} p_r p_t [\cos 2(\theta_j - \delta) + \cos 2\delta]$$

$$a_{1,i} = \frac{N_{OBC,i}(1 + p_r p_t \cos 2\delta) - a_o(\theta_{OBC}) - a_2(dn_{obc,i} - dn_{sv,i})^2}{(dn_{obc,i} - dn_{sv,i})}$$

$N_{sc,i,j}$  = Scene Radiance ( $\text{mW/m}^2\text{-sr-cm}^{-1}$ )

$P_{sm}$  = Planck radiation function

$N_{OBC,i}$  = Radiance of the On-Board Calibrator Blackbody

$i$  = Scan Index,  $j$  = Footprint Index

$\theta$  = Scan Angle.  $\theta = 0$  is nadir.

$dn_{i,j}$  = Raw Digital Number in the Earth View

$dn_{sv,i}$  = Space view counts offset.

$a_o$  = Radiometric offset.  $a_{1,i}$  = Radiometric gain.

$a_2$  = Nonlinearity

$p_{rpt}$  = Polarization Factor Product

$d$  = Phase of the polarization

## Radiometric Accuracy Equation

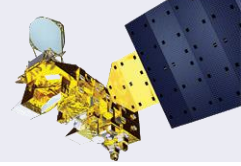
$$\sigma_{N_{sc}}^2 = \left( \frac{\partial N_{sc}}{\partial p_r p_t} \Delta p_r p_t \right)^2 + \left( \frac{\partial N_{sc}}{\partial \delta} \Delta \delta \right)^2 + \left( \frac{\partial N_{sc}}{\partial T_{sm}} \Delta T_{sm} \right)^2 + \left( \frac{\partial N_{sc}}{\partial \theta} \Delta \theta \right)^2 + \left( \frac{\partial N_{sc}}{\partial \epsilon_{OBC}} \Delta \epsilon_{OBC} \right)^2 + \left( \frac{\partial N_{sc}}{\partial T_{OBC}} \Delta T_{OBC} \right)^2 + \left( \frac{\partial N_{sc}}{\partial a_2} \Delta a_2 \right)^2 + \left( \frac{\partial N_{sc}}{\partial dn} \Delta dn \right)^2$$

T. Pagano et al., "Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS)," IEEE TGRS, Volume 41, No. 2, February 2003, p. 265

T. Pagano, H. Aumann, K. Overoye, "Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003

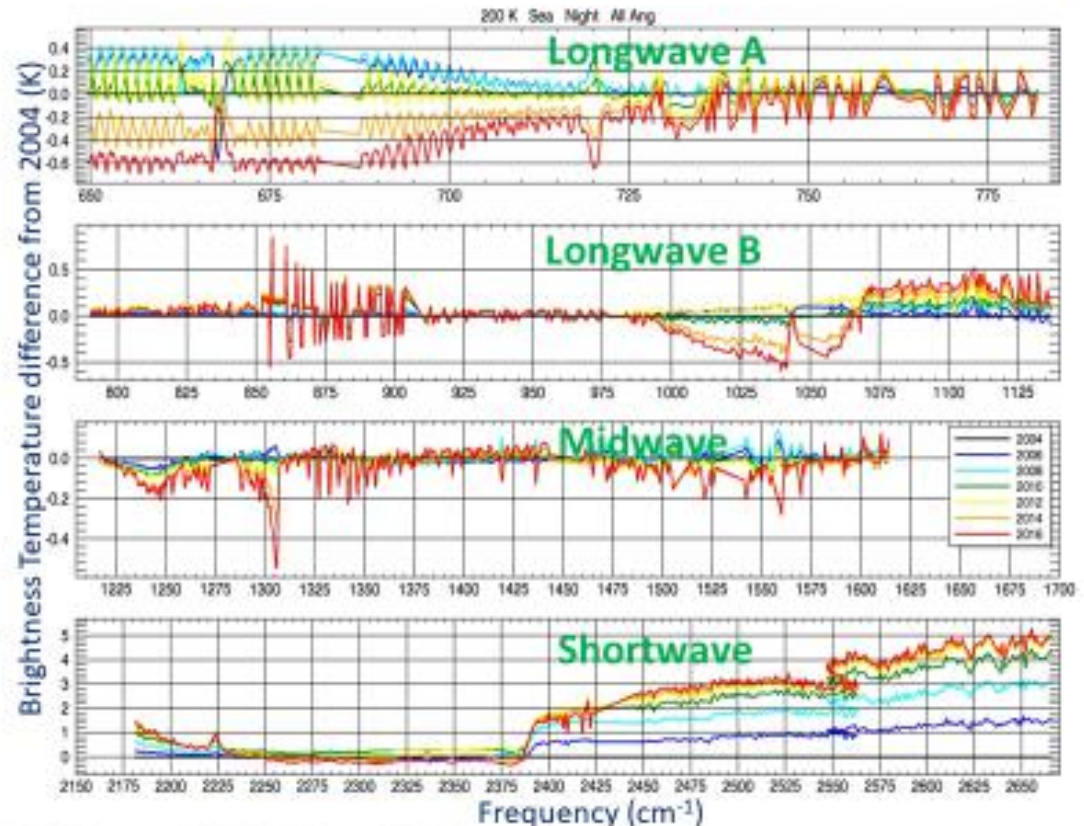


# Trends seen in AIRS Calibration in Cold Scenes (DCC's)



## AIRS Trends 2

- The same data as the previous image but now shown as difference from a 2004 baseline.
- The stratospheric interannual differences are real
- A/B detector differences up to  $\pm 0.6$  K are very obvious but are actually decreasing
- Shortwave trend is up to 5 K.
- There's also a trend up to  $0.3 \text{ K} \sim 1100 \text{ cm}^{-1}$ .



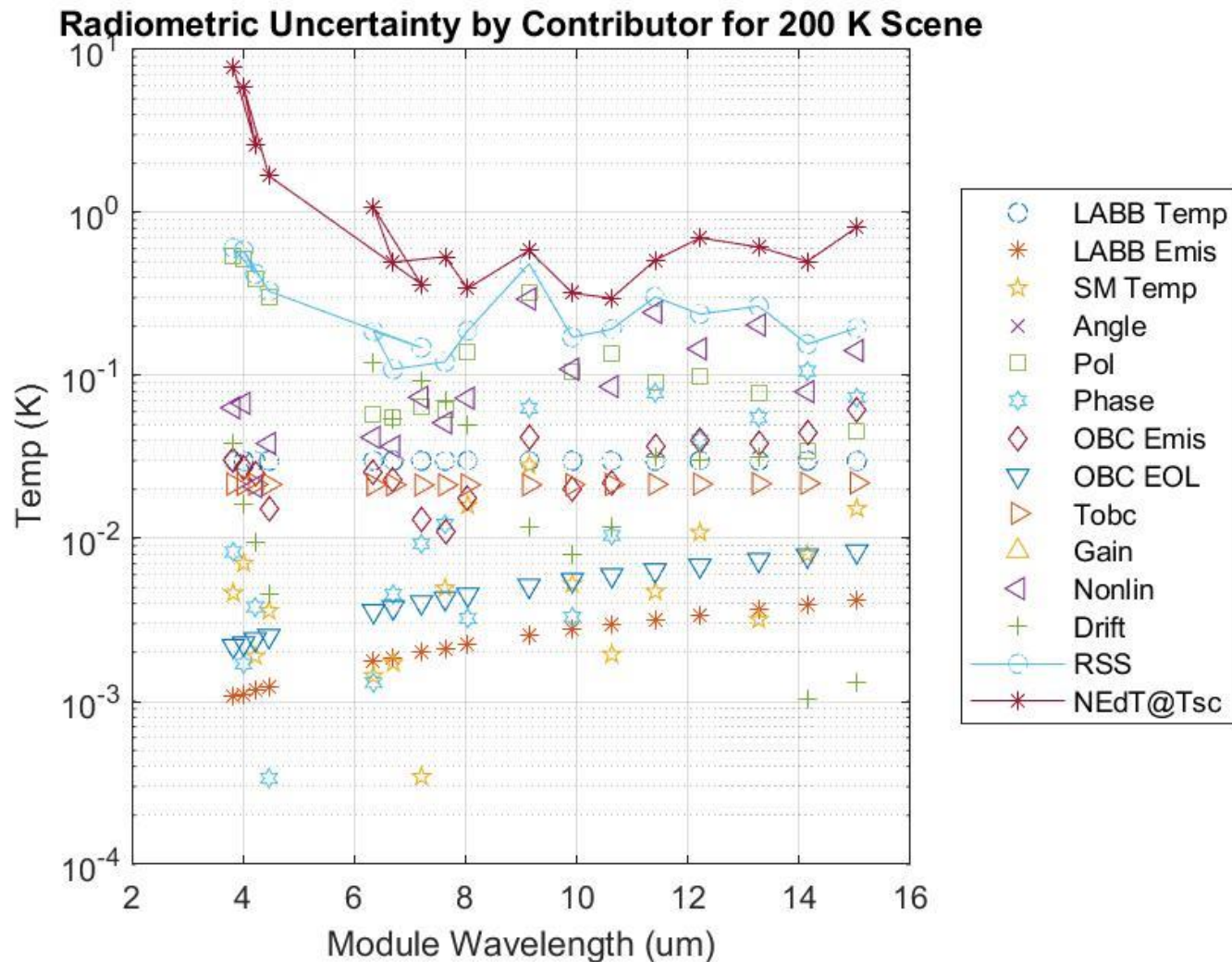
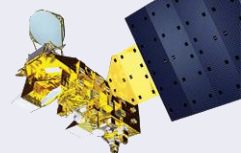
8/10/17

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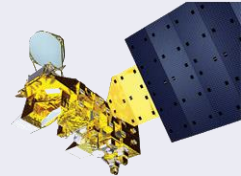
13

Evan Manning, October 2017 Science Team Meeting

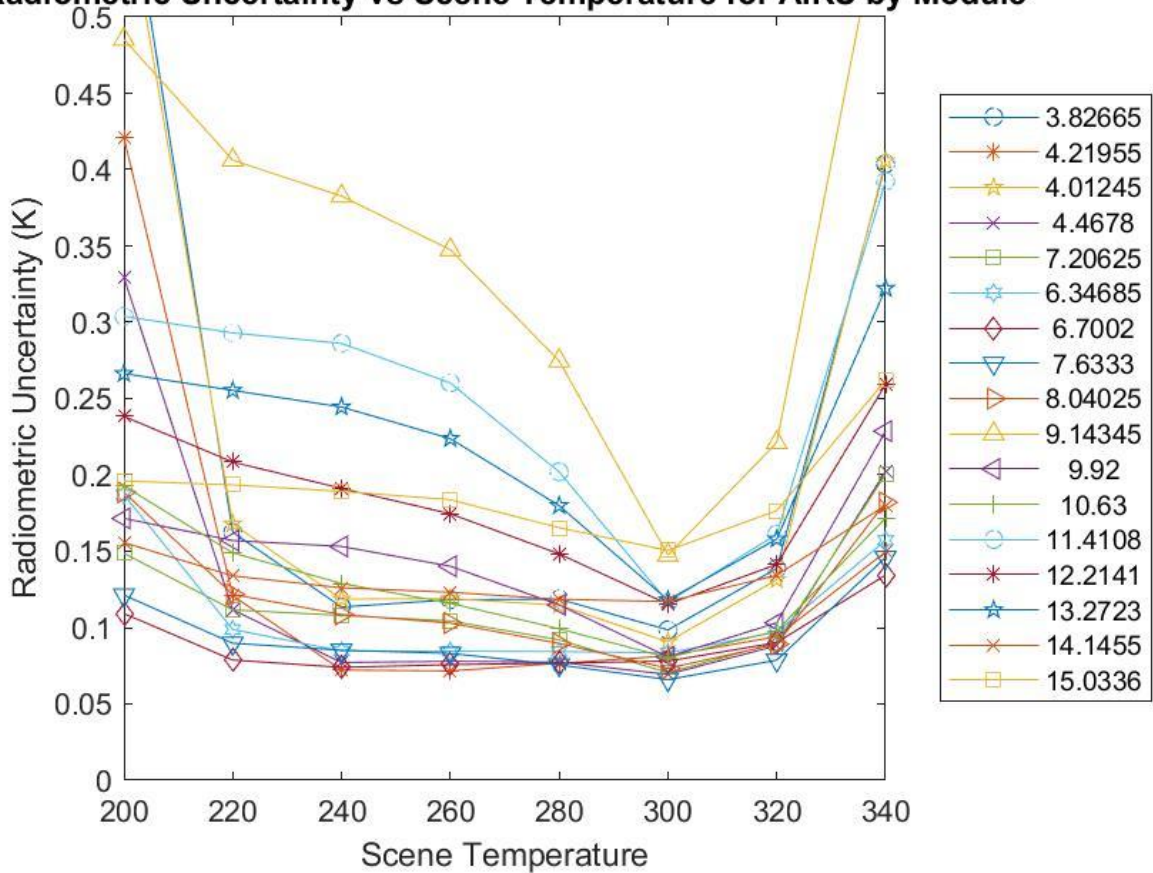
# High Uncertainty in Mirror Polarization Impacts 4 $\mu$ m Accuracy in Cold Scenes (200K)



# Uncertainty is greatest at temperature extremes

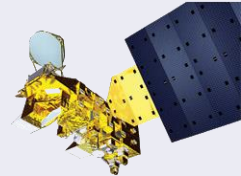


Radiometric Uncertainty vs Scene Temperature for AIRS by Module





# 4 Spaceviews Enable Calibration of Mirror Polarization. Roll provides Validation.



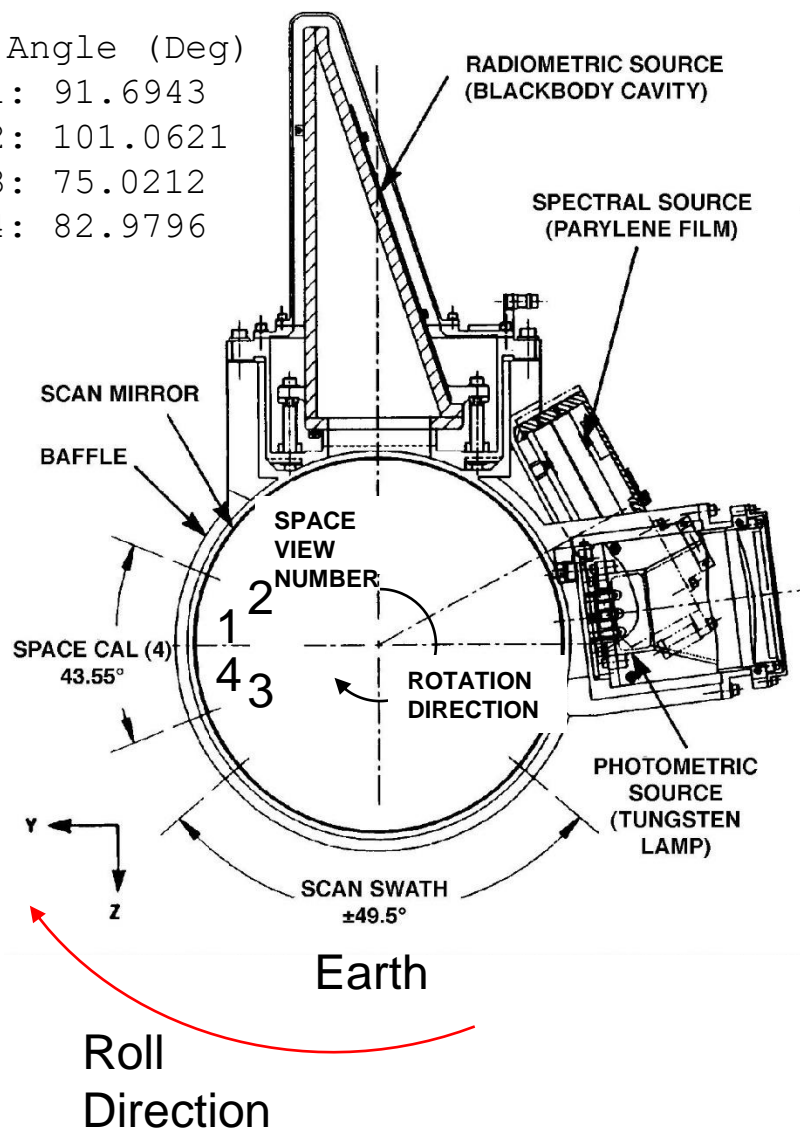
SV Angle (Deg)

SV1: 91.6943

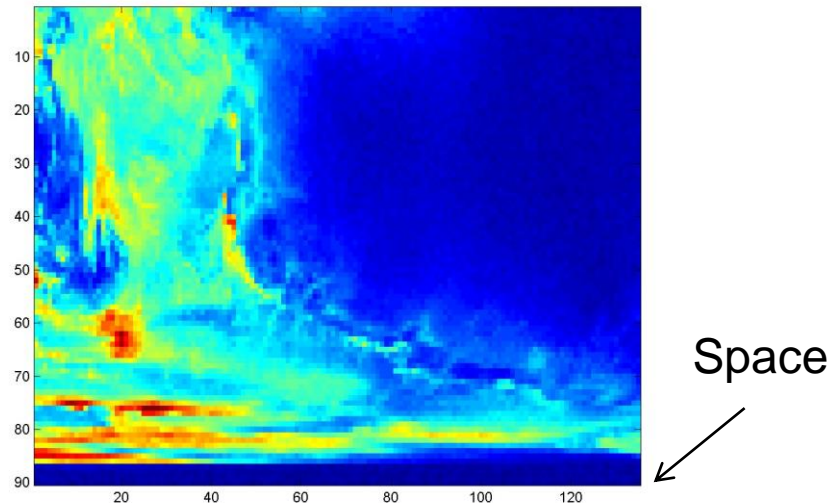
SV2: 101.0621

SV3: 75.0212

SV4: 82.9796

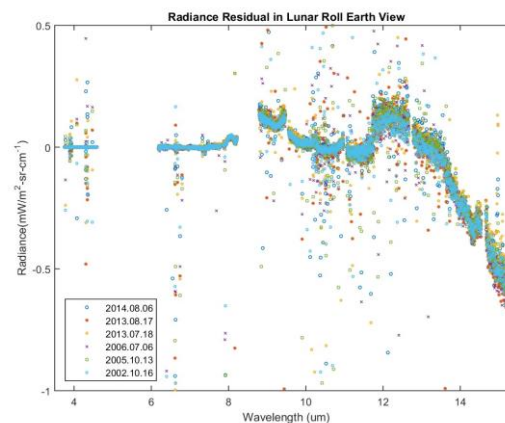


BT Ch 2333, 2616  $\text{cm}^{-1}$



Earth View – Space View Radiance

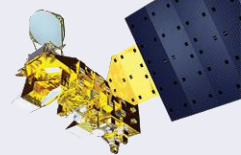
Radiance  
( $\text{mW}/\text{m}^2\text{-sr-cm}^{-1}$ )



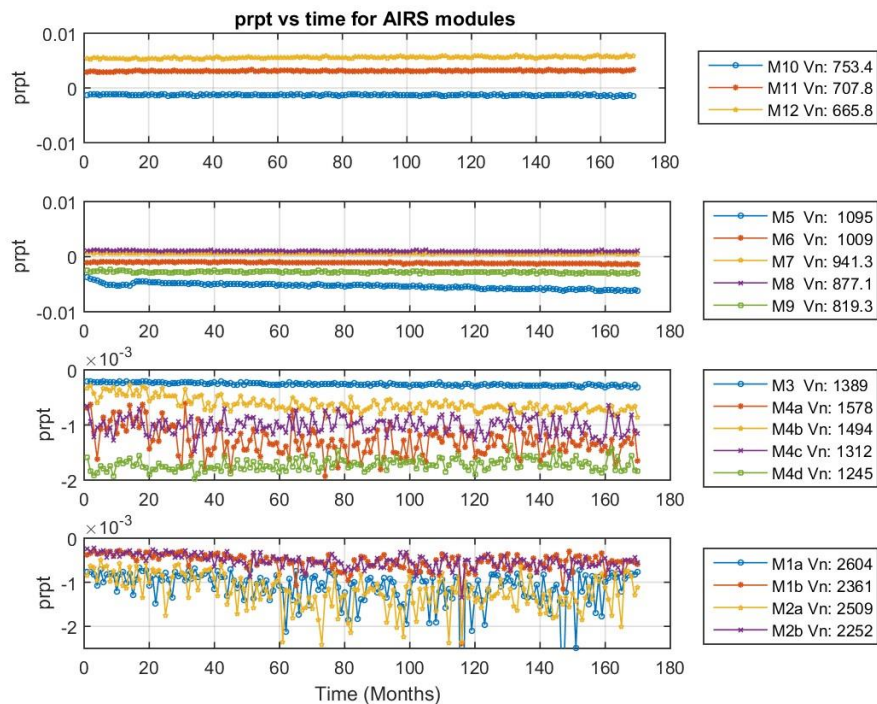
$$(dn_x - dn_{s1})a_1 = -P_{sm}p_rp_t[\cos 2\delta \cos 2\theta_x + \sin 2\delta \sin 2\theta_x + \cos 2\delta] \quad 8$$



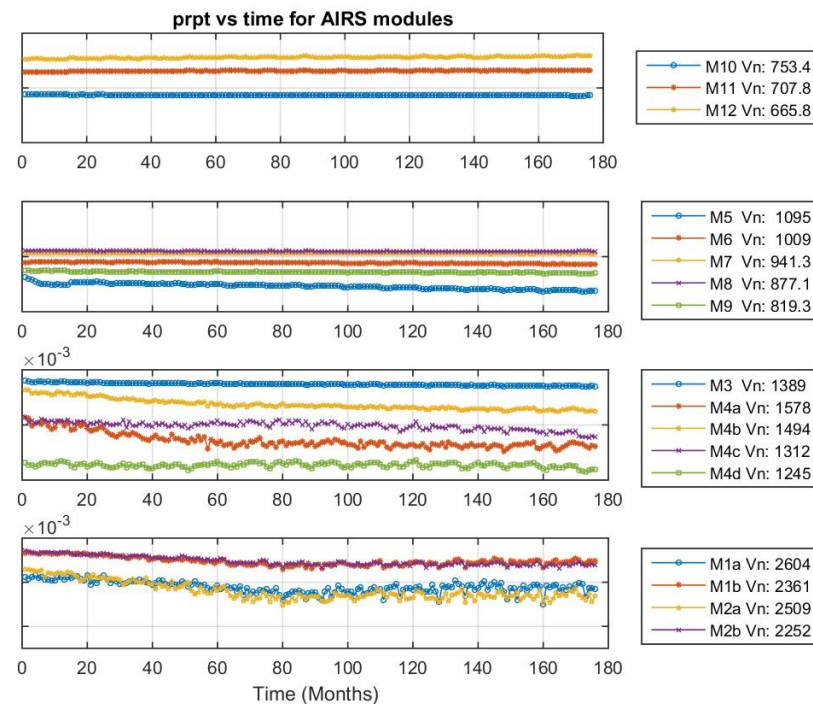
# Space Views Enable In-orbit Characterization of AIRS Mirror Polarization Trends



## One Day Per Month

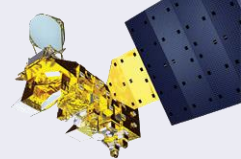


## 30d Average Day Per Month



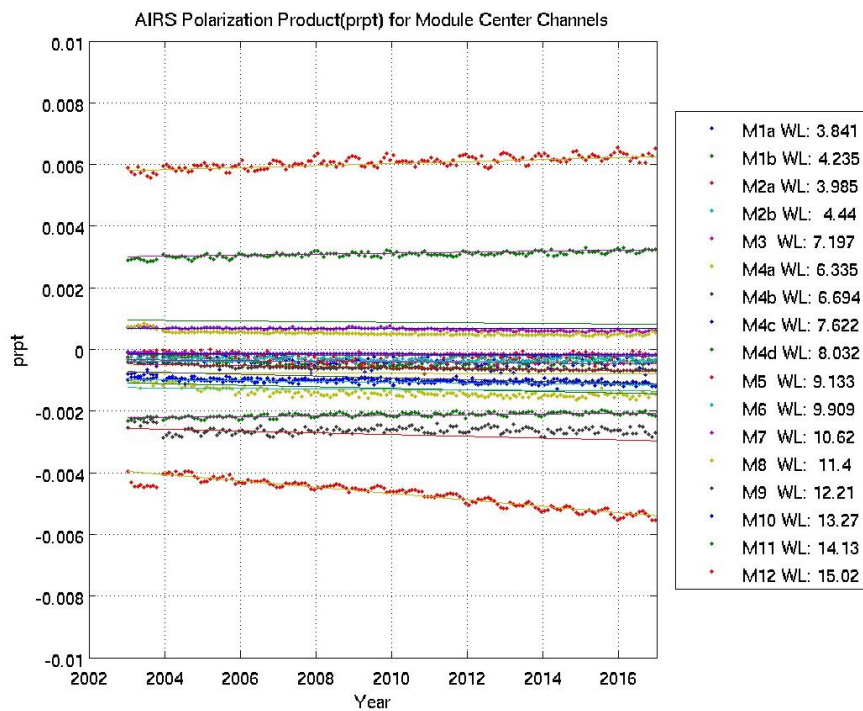
Space views for all channels for entire mission averaged by day provided by Evan Manning

# Module Center Channels $p_r p_t$ and Phase vs time

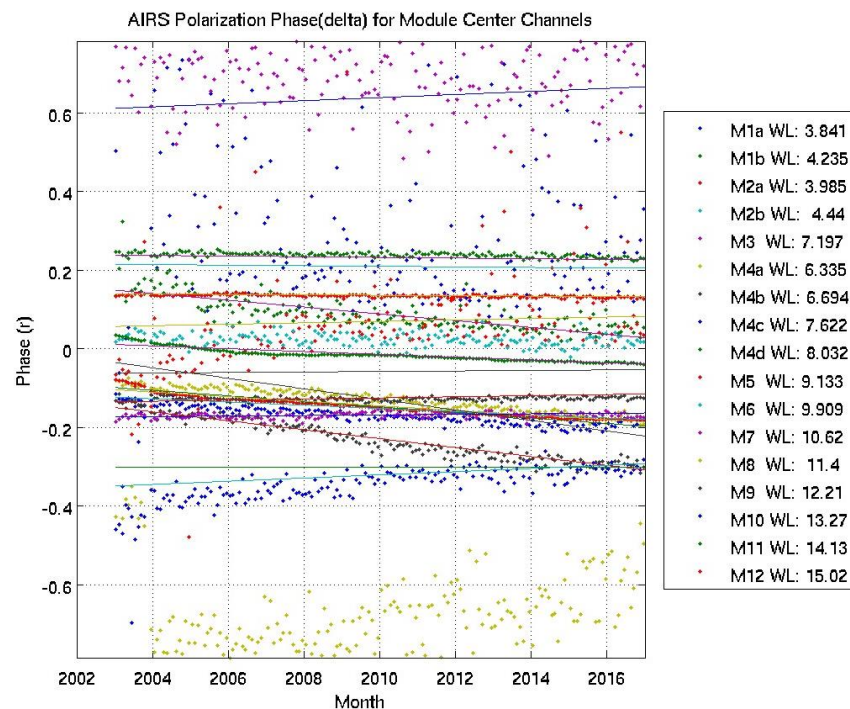


Polarization and phase per month and linear fit

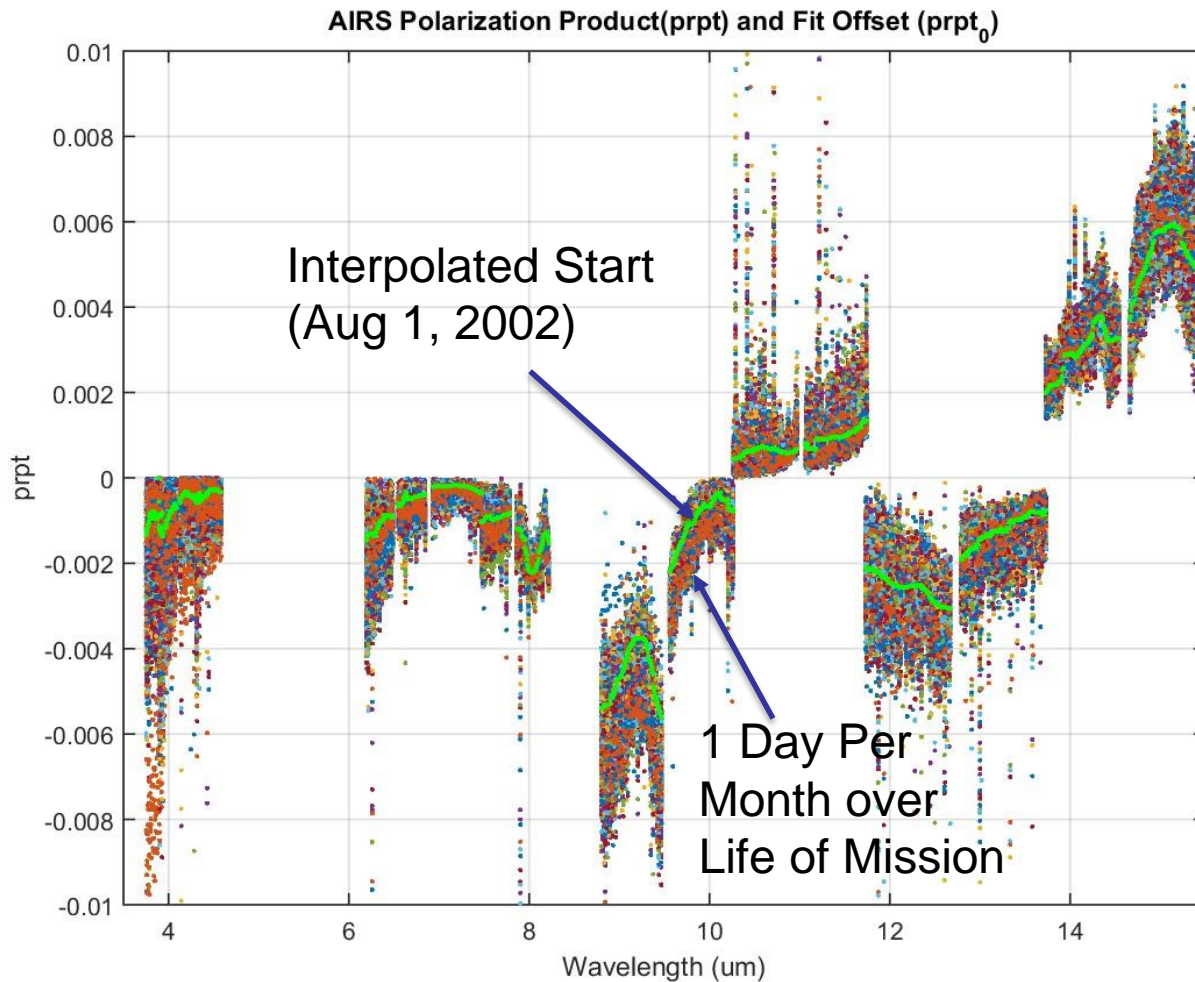
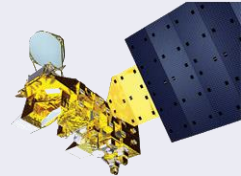
$p_r p_t$



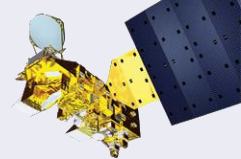
Phase



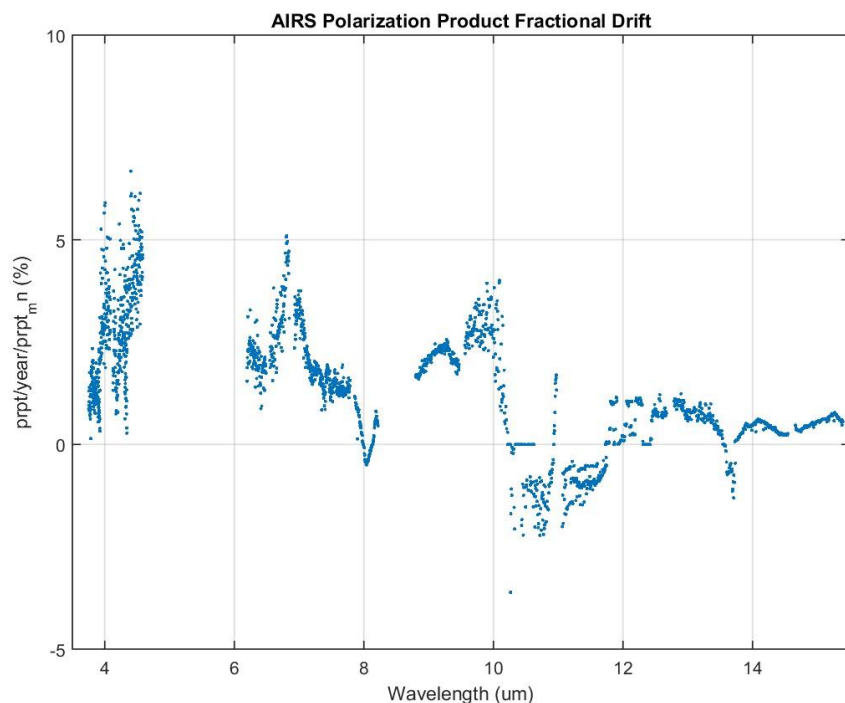
# Polarization and Phase Derived from SV Data over Entire Mission



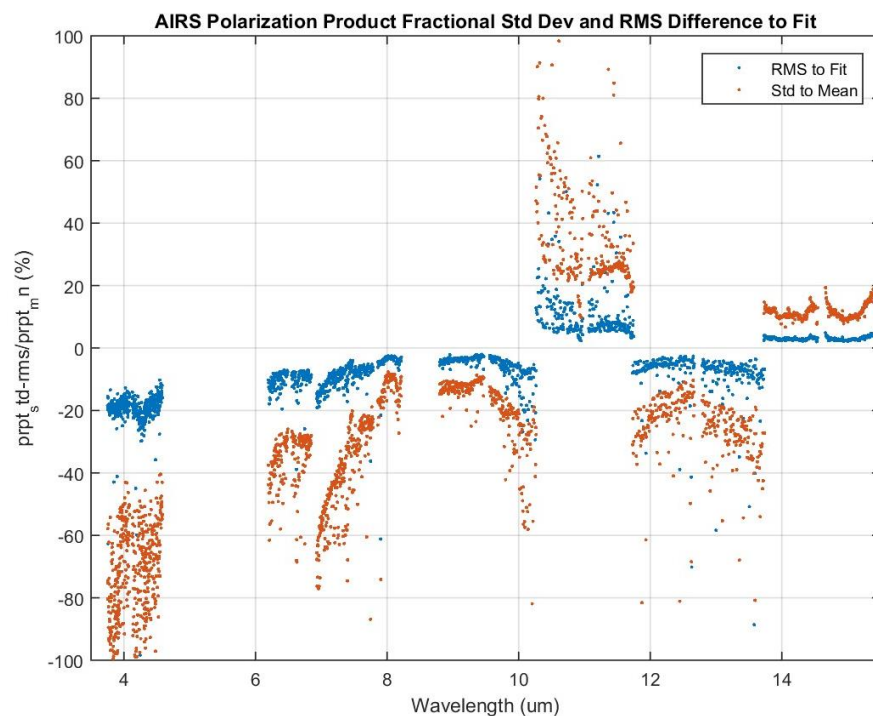
# Linear fit gives annual trend. Time dependent polarization reduces errors.



Trend in polarization is up to 5% of nominal per year

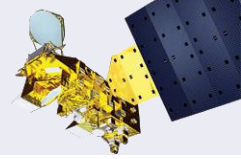


Time dependent polarization fit (blue) reduces errors compared to static (red)



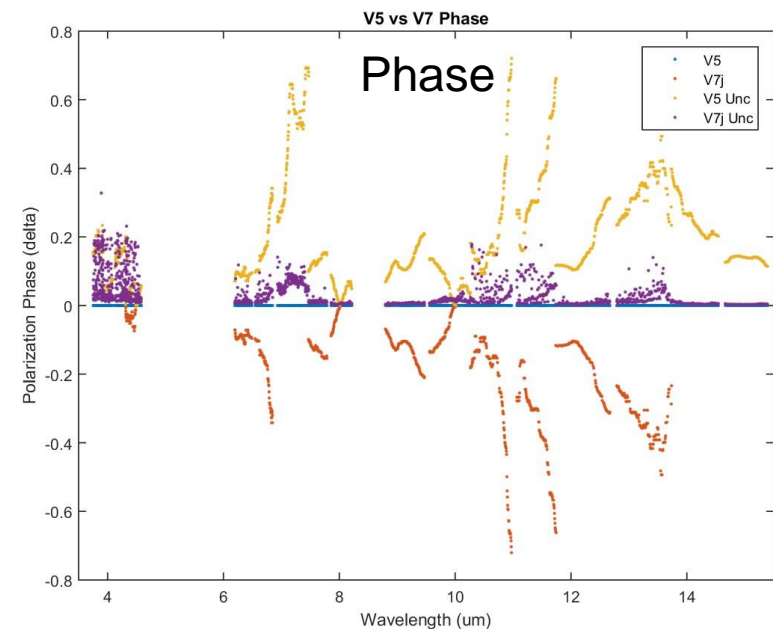
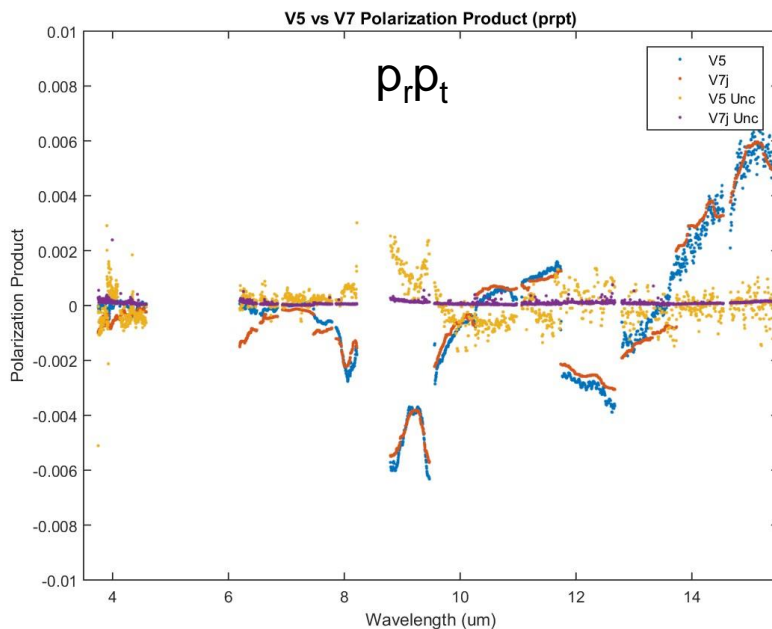


# V5 vs v7j Polarization



## V7j Polarization Factor Product and Phase

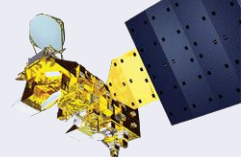
- Monthly averaged space views (Manning ADF 917)
- Fit to cal equation as a function of prpt and phase (Weiler ADF 741)
- Time dependent coefficients (t=0 shown below)
- 20 point smooth over individual modules
- Uncertainty is rms dev of fit to linear trend



- Average prpt comparable v5 and V7
- More discrete module boundaries in V7

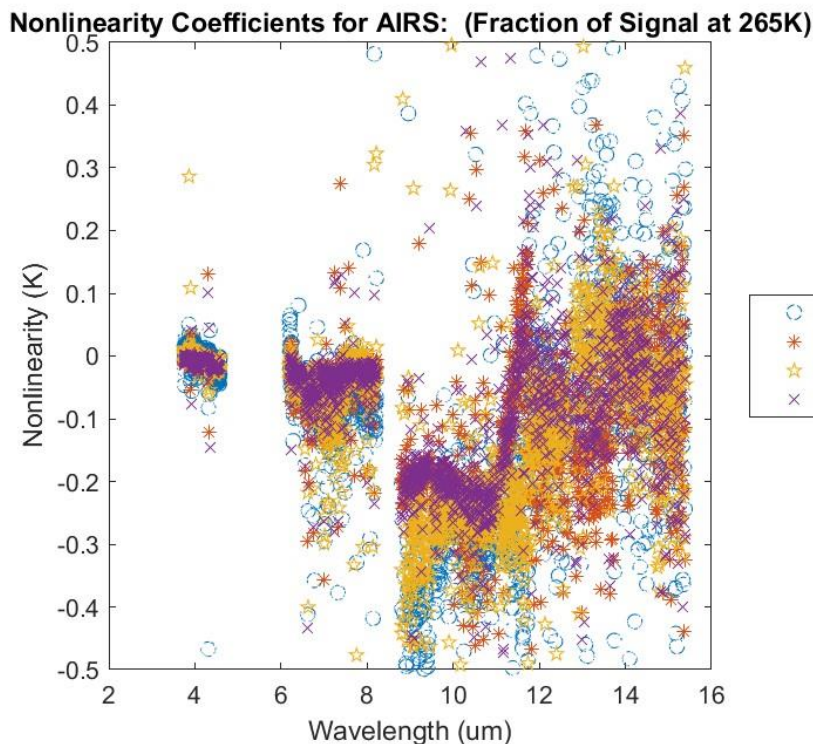
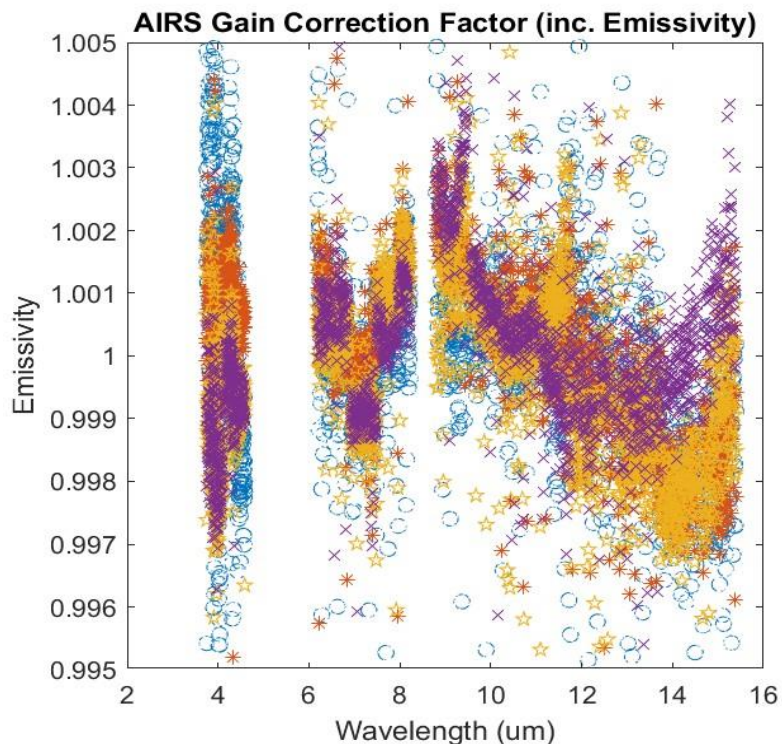
- Phase = 0 in v5

# Preflight Stepped Linearity Test Used to Derive OBC BB Emissivity and Nonlinearity



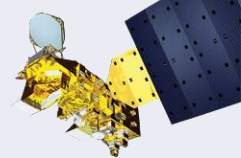
## Effective Emissivity

## Nonlinearity



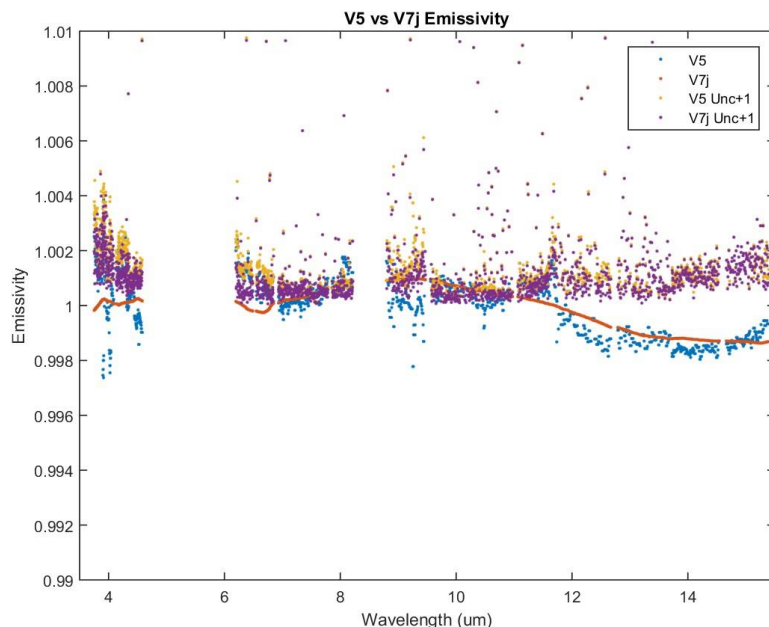
Temp(K)	205	220	230	240	250	265	280	295	310
A Side	1687	1692	1693	1698*	1704	1707*	1718	1719	1727*
B Side	1688	1689	1696	1697	1705	1706	1715	1720	1726
1698: Saturated M4, 1707: zeros, 1727: low gain. These three test not used in analysis									
A Side: 40deg	1830	1841	1844	1849	1852	1857	1860	1865*	1872
B Side: 40deg	1829	1842	1843	1850*	1851*	1858	1859	1866	1871
1865: Anomalous, 1850 Missing, 1851 Scan Dropout. These three test not used in analysis									

# V5 vs v7j Emissivity and Nonlinearity



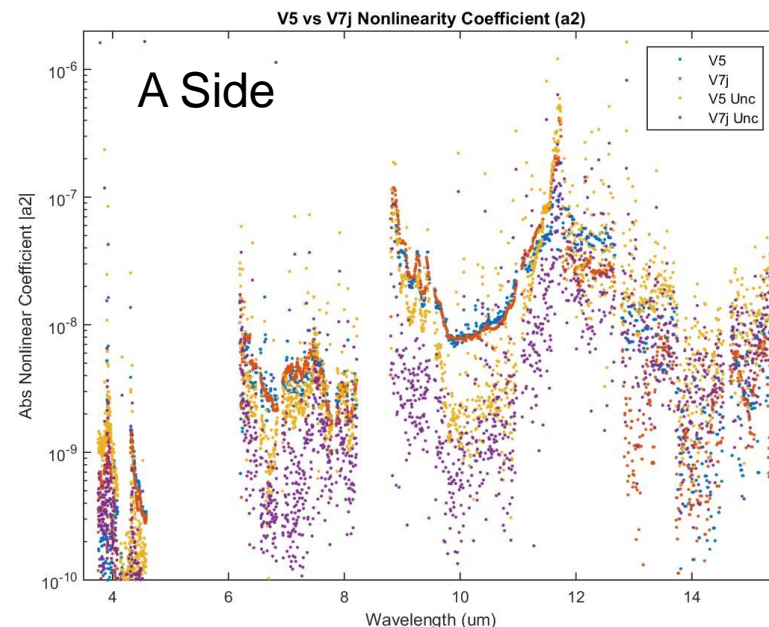
## V7j Emissivity

- Sorted by Wavelength
- Median smooth over 500 channels
- Averaged over all Tests



## V7j Nonlinearity

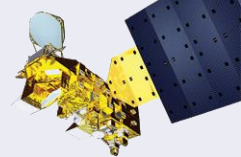
- Sorted by Module
- Median smooth 20 channels
- Averaged over all test
- A and B Separate



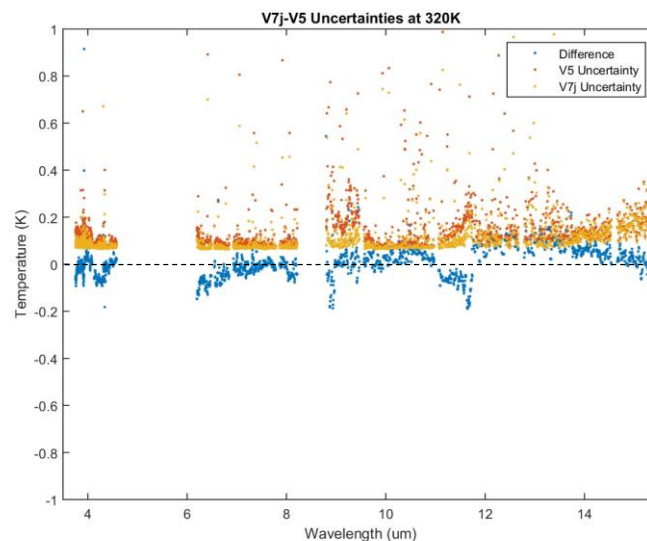
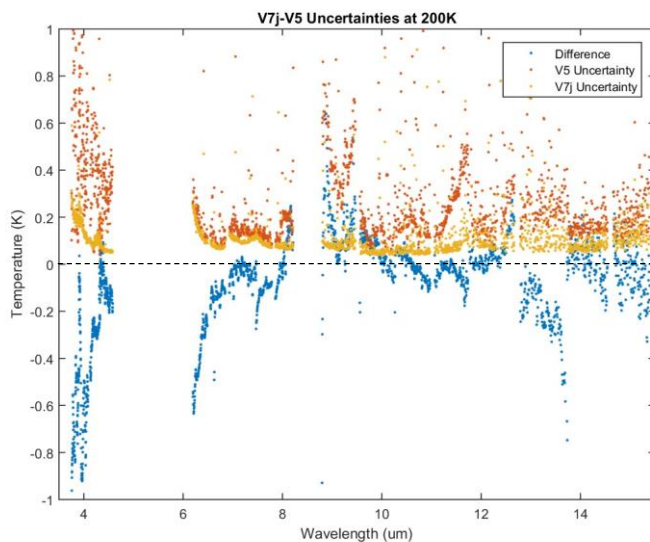
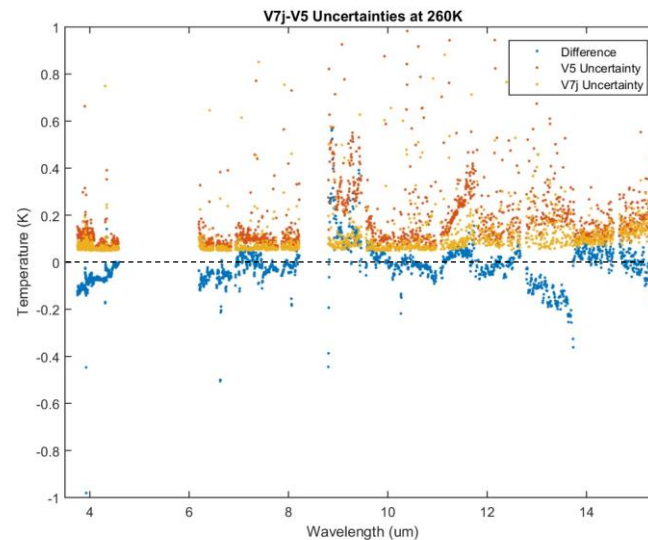
- Errors comparable V5 and V7
- Average emissivity closer to unity
- No module boundary discontinuities

- Errors comparable V5 and V7
- Average emissivity closer to unity
- No module boundary discontinuities

# Calculated V7j-V5 Bias and Uncertainties by Channel at 3 Scene Temperatures

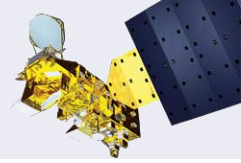


- Significant differences at low scene temperature due to polarization changes
- Less than 200 mK errors for warmer scenes

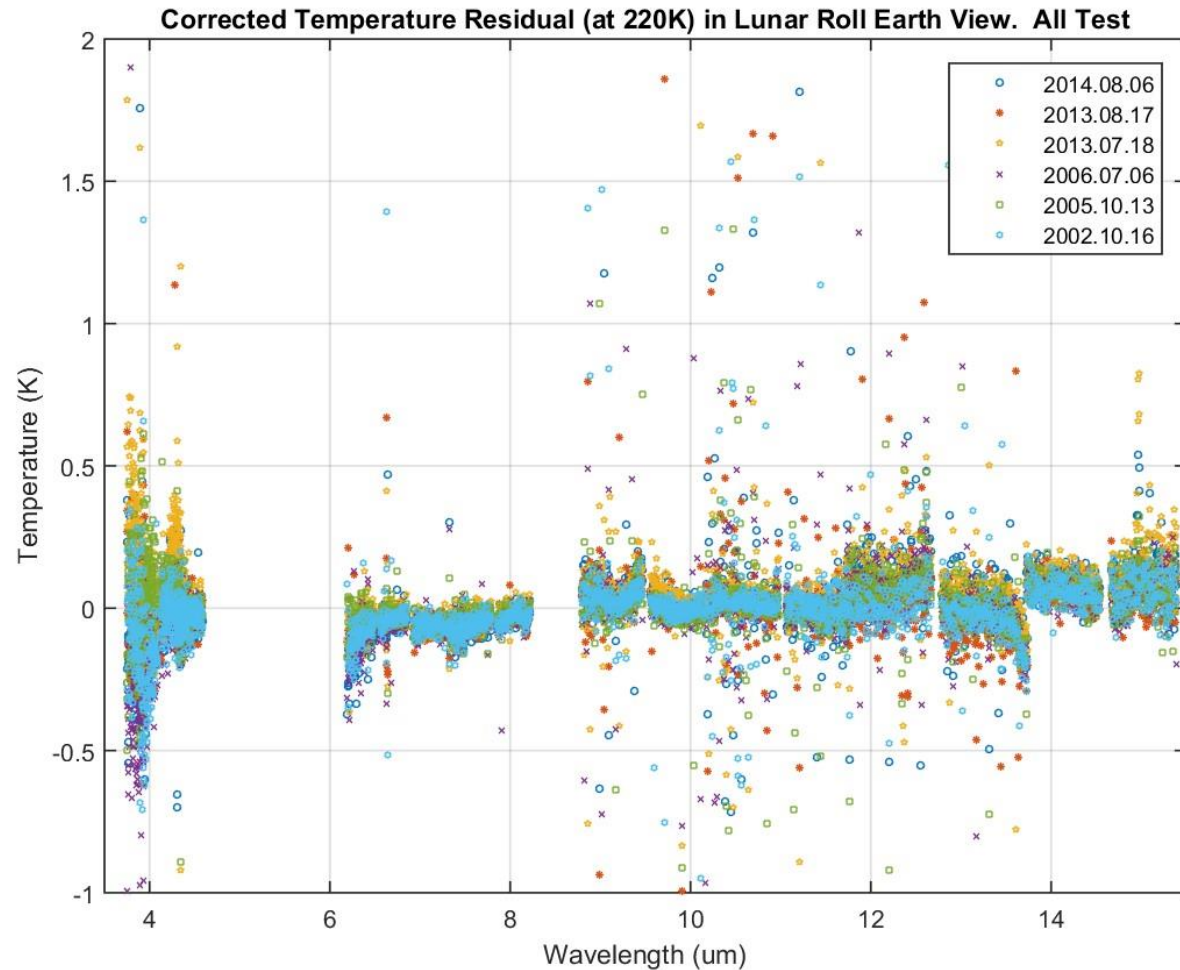




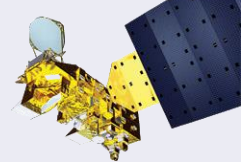
# Coefficients derived from space views applied to roll test produce low errors



Derived  
radiance in  
Earth Viewport  
of deep space  
(spacecraft roll  
maneuver)  
expressed in  
terms of  
temperature at  
220K

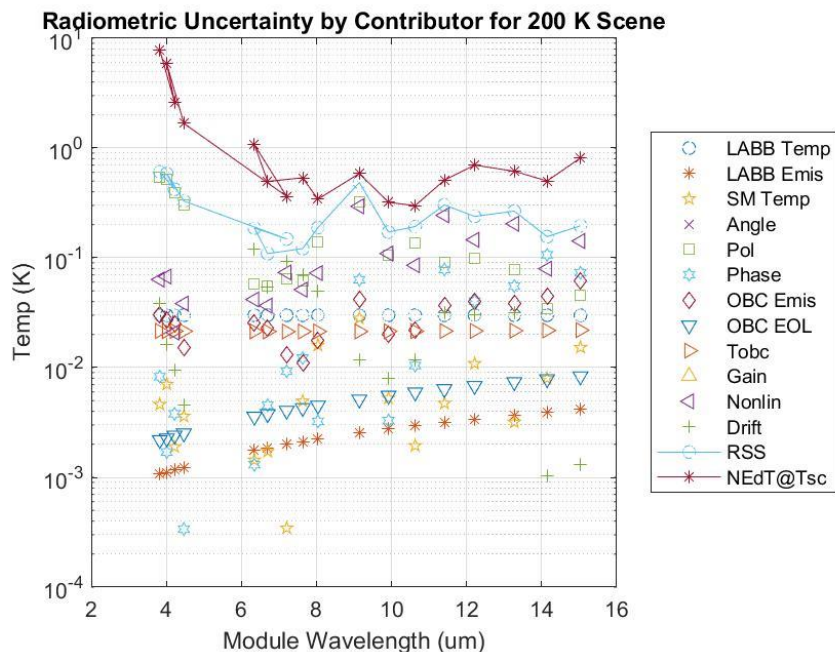


# Radiometric Uncertainty by Contributor at 200K Scene Temperature

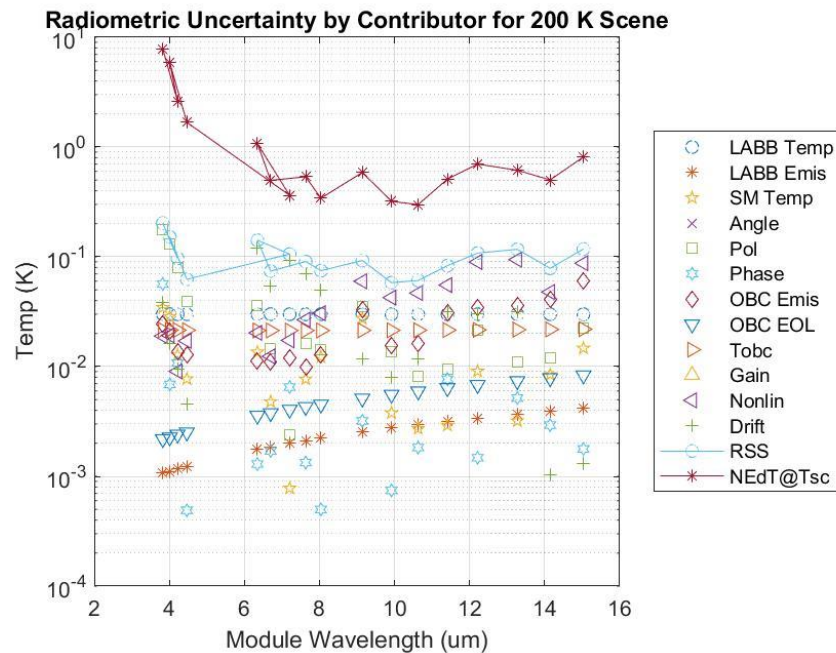


V7j uncertainties for prpt and nonlinearity much smaller at cold scene temperatures

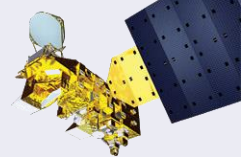
v5



v7j



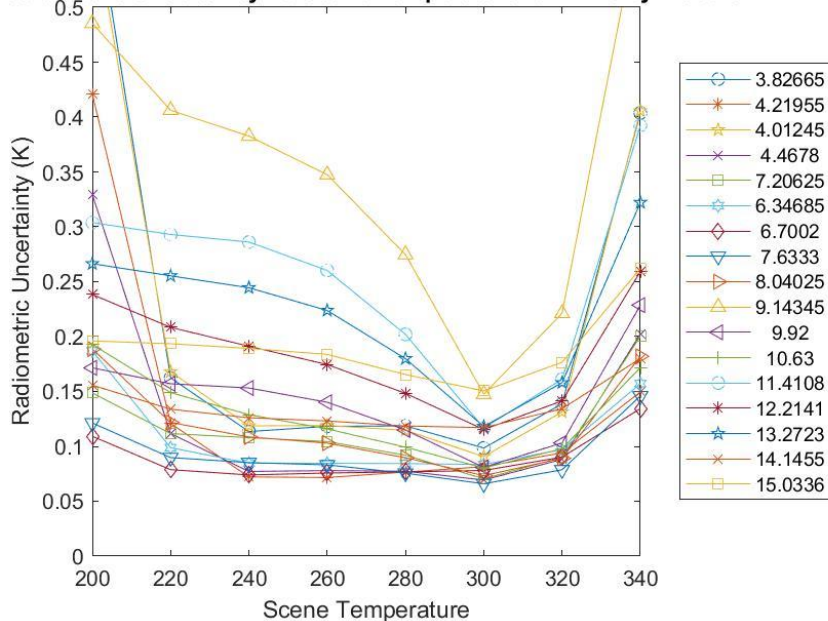
# Radiometric Uncertainty vs Temperature by Module for Uniform Scenes



- V7j uncertainty smaller and less scene dependent

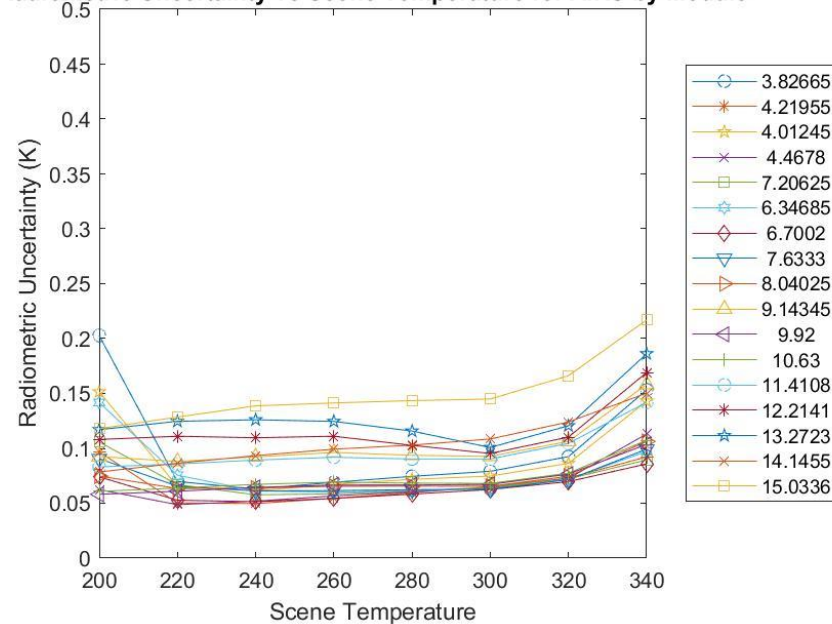
v5

Radiometric Uncertainty vs Scene Temperature for AIRS by Module

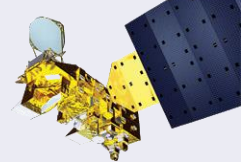


v7j

Radiometric Uncertainty vs Scene Temperature for AIRS by Module

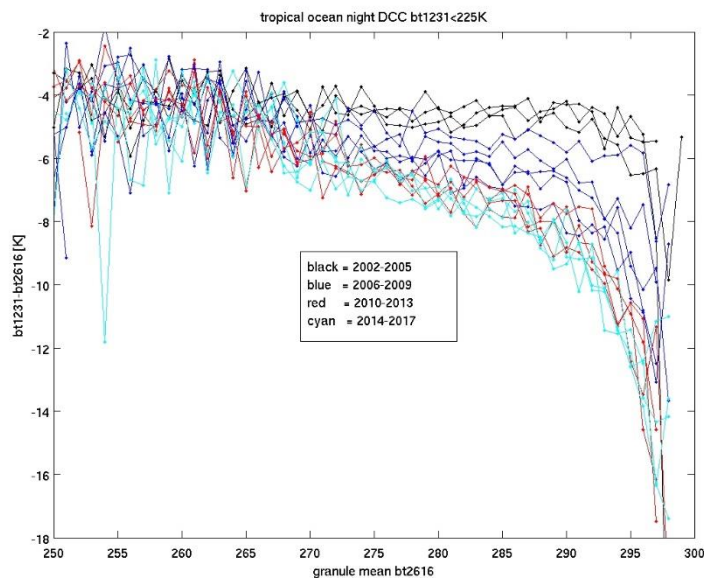


# Example of Potential Calibration Error in Non-Uniform Scenes



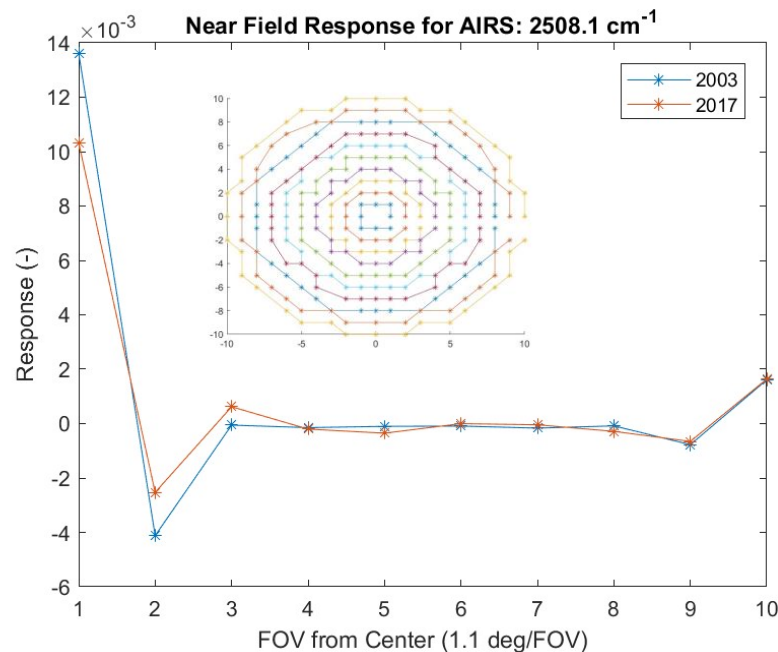
- BT 2616  $\text{cm}^{-1}$  – BT 1231  $\text{cm}^{-1}$  shows trend with time
- Trend shows increasing dependence on granule average temperature (Aumann)
- Spatial analysis of differences shows change in near field response
- Potential Causes: Mirror Scatter Degradation, Defocus
- PRELIMINARY

BT1231-BT2616 Viewing Cold Scenes < 225K vs Time & Granule Temperature while viewing DCCs (Aumann)

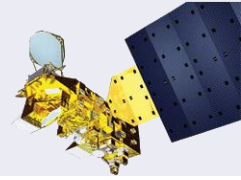


## Regression Analysis

- Fit difference between  $L(2508) - P(T_{1231}, \nu_n = 2508 \text{ cm}^{-1})$ 
  - To sum of signals from near field
  - L1B Extracted Data from Evan Manning







- AIRS radiometric accuracy at low temperatures driven by knowledge of the mirror polarized emission ( $p_r, p_t$  and  $\delta$ )
- View of space during normal scanning operations enables in-flight derivation of polarized emission
- Terms applied to earth view during spacecraft roll show low residual errors
- Significant improvement over v6 errors
- Worst problem (biggest improvement) at short wavelengths and cold temperatures. *Not enough to explain all errors observed with DCCs*
- Next Steps:
  - Test: Examine sample and ACDS data sets compared to prior versions
  - Validate:
    - Check trends on Deep Convective Clouds
    - Revisit validation of polar regions
  - Cross-compare
    - Compare with IASI and CrIS
  - Accuracy assumes uniform scenes. Next step to look at accuracy in non-uniform scenes.